

ECE 413/513 –RADIO FREQUENCY IC DESIGN

COURSE INTRODUCTION

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COURSE OUTLINE

Course Site : <http://lumerink.com/courses/ece513/f18/ECE513.htm>



COURSE TOPICS

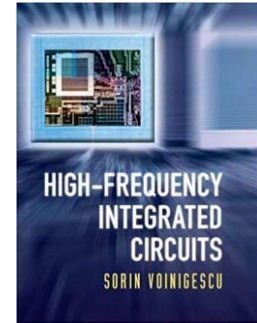
- Radio Frequency (RF) Transceivers: Basics and Architectures
- Fundamentals:
 - Two-port networks
 - Distortion and Noise
 - Matching, Smith Chart use
 - RF Link budget analysis
- High-frequency MOSFETs
- Tuned amplifier design and analysis
- Low-noise amplifiers (LNA)
- Mixers
- Oscillators (PLLs covered in ECE 504)
- Power Amplifiers (if time permits)



REFERENCES

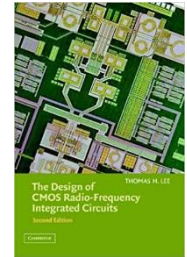
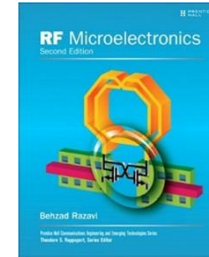
- **Textbook:**

- [High-Frequency Integrated Circuits](#), S. Voinigescu, 1st edition, Cambridge, 2013.



- **Additional References:**

- [RF Microelectronics](#), B. Razavi, 2nd Edition, Prentice Hall, 2011
- [The Design of CMOS Radio-Frequency Integrated Circuits](#), T. H. Lee, 2nd edition, Cambridge, 2003.



COURSE PEDAGOGY AND GRADING

- Combination of lecture notes and slides
 - Lecture notes to be posted online
 - Additional slides, Matlab code etc. will also be posted on the site
- Workload (Grading)
 - Homeworks (25%)
 - Midterm Exam (25%)
 - Project 1 (25%)
 - Final Exam or Project 2 (25%)
- Cadence is used for design-based HWs and Projects



COURSE POLICIES

- No late work
- Neither the final exam nor final project will be returned at the end of the semester
- No internet surfing in class on any device
- Plagiarism and outsourcing (!) of work is not acceptable (See UoI Policy).
- See detailed policies on the [course site](#)



ANALOG IC COURSES AT UI

ECE 410

- Microelectronics II

ECE 515

- Analog IC Design

ECE 517

- Mixed-Signal IC Design

ECE 513

- RF IC Design

ECE 519

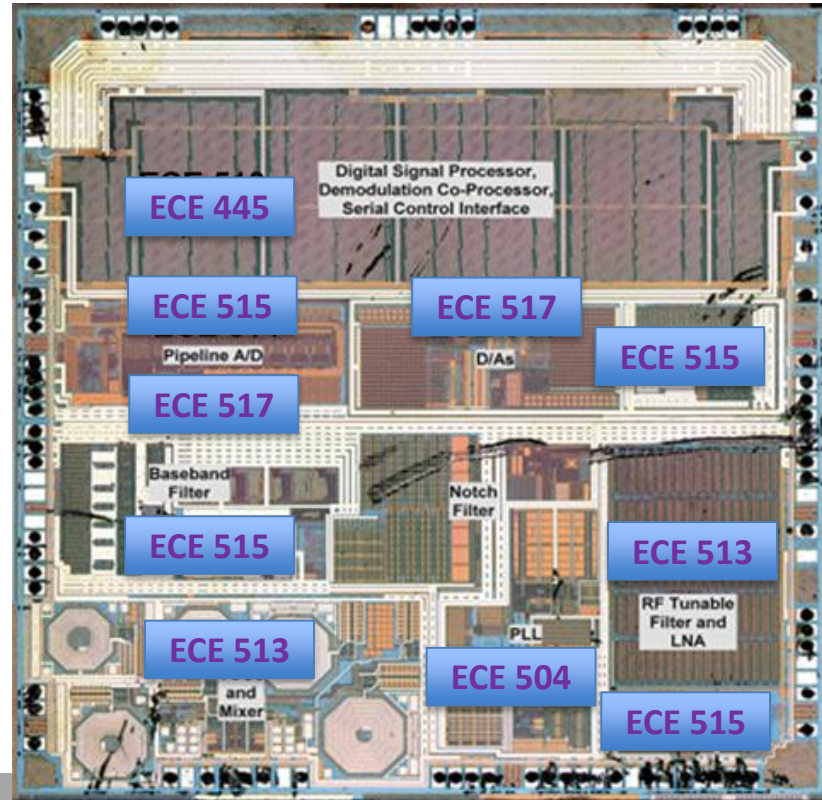
- CMOS Imager Design

ECE 504

- PLL and High-speed Link Design

ECE 504-X

- Other Advanced Topics in IC Design



REVIEW

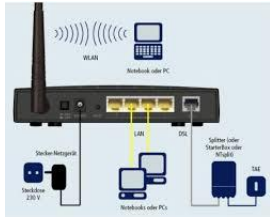
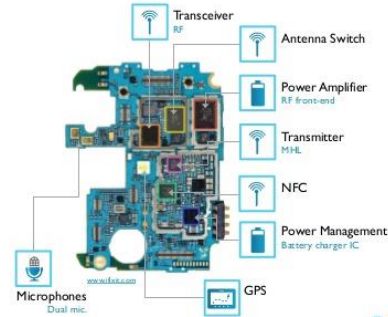
- Brush up on Analog Circuit Design basics (ECE 410)
 - <http://lumerink.com/courses/ece5411/s11/Lectures.htm>
- Signals and Systems
 - Frequency domain understanding, modulation and demodulation from your undergrad textbook
- Review Smith Chart
 - <https://www.youtube.com/watch?v=hmqM8PnUkmo&t=380s>



WIRELESS TRANSCEIVERS



Samsung Galaxy S4



<https://pt.slideshare.net/SatyaHarish1/wearables-show-march-2015>



- 'Radio' transceivers are ubiquitous and indispensable
- Cellular, internet of things, satellite, military, RADAR,.....
- Recent activity in 5G wireless extended to 28GHz, 60GHz and higher frequency bands



SPECTRUM ALLOCATION

UNITED STATES FREQUENCY ALLOCATIONS THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

AERONAUTICAL MOBILE	INTER-SATELLITE	RADIO ASTRONOMY
AERONAUTICAL MOBILE SATELLITE	LAND MOBILE	RADIODIFFRACTION SATELLITE
AERONAUTICAL RADIODIFFRACTION	LAND MOBILE SATELLITE	RADIOLOCATION
AMATEUR	MARITIME MOBILE	RADIOLOCATION SATELLITE
AMATEUR SATELLITE	MARITIME MOBILE SATELLITE	RADIODIFFRACTION
BROADCASTING	MARITIME RADIODIFFRACTION	RADIODIFFRACTION SATELLITE
BROADCASTING SATELLITE	METEOROLOGICAL	SPACE OPERATION
BROADCASTING/AMATEUR SATELLITE	METEOROLOGICAL SATELLITE	SPACE RESEARCH
FIXED	MOBILE	STANDARD FREQUENCY AND TIME SIGNAL
FIXED SATELLITE	MOBILE SATELLITE	STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

FEDERAL EXCLUSIVE	FEDERAL NON-FEDERAL SHARED
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NON-FEDERAL DESIGNATION

ALLOCATION USAGE DESIGNATION

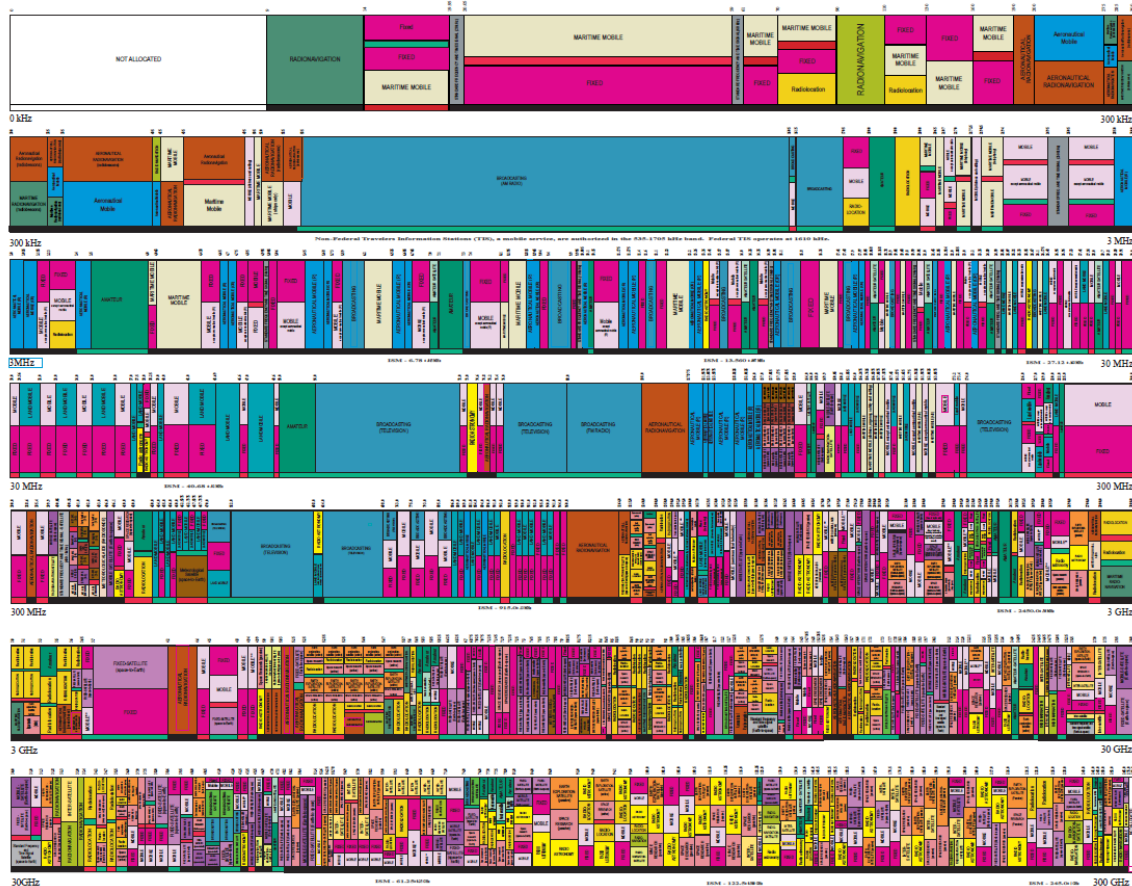
SERVICE	REMARKS	REstriction
Fixed	Fixed	Fixed service
Mobile	Mobile	For Digital with other services

The National Spectrum Allocation Plan of the United States (revised in 2016) is the result of a process that began in 2002, and is based on the National Spectrum Allocation Plan of 2002. The National Spectrum Allocation Plan of 2002 is the result of a process that began in 2002, and is based on the National Spectrum Allocation Plan of 2002.



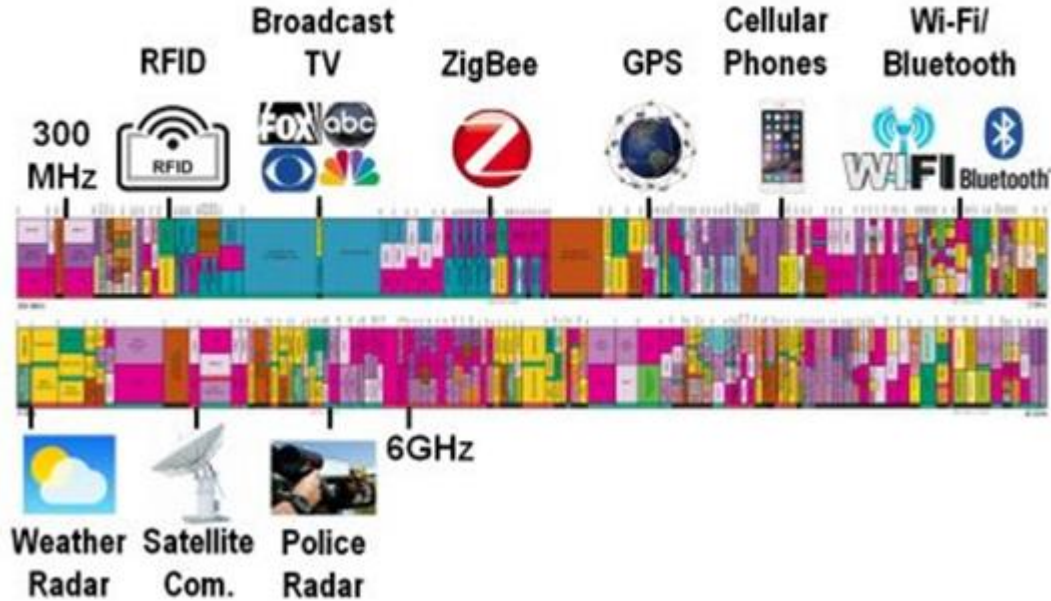
U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management

https://www.ntia.doc.gov/files/ntia/publications/january_2016_spectrum_wall_chart.pdf



RF SPECTRUM ALLOCATION

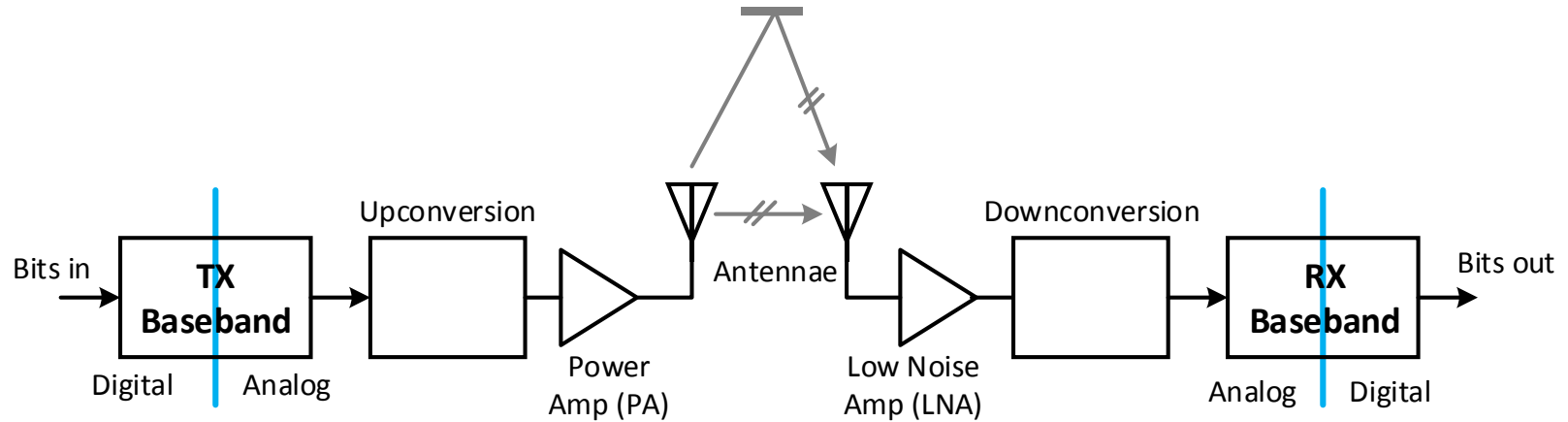
Existing Commercial Frequency Allocation



<https://www.ee.washington.edu/spotlight/uw-radio-researchers-break-world-record-with-full-duplex-communication/>



RF TRANSCEIVERS

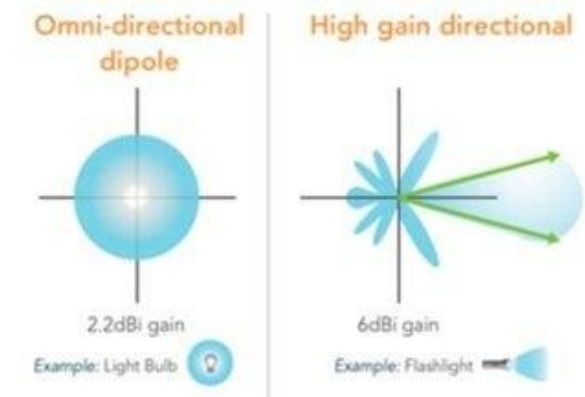


ANTENNA BASICS



ANTENNAS

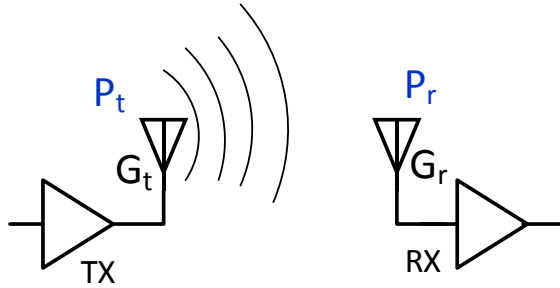
- Antennas ‘match’ the energy on a transmission line to a propagating wave in free space (377Ω impedance)
 - Essentially a passive device with an input impedance, efficiency, gain and directivity
- Higher gain implies higher directivity.
 - Omnidirectional antenna has lower gain (think of light bulb) than an antenna with high directivity (think of flashlight)
- Efficient antennas have dimensions roughly equal to the free space propagation wavelength (λ)



Ali Niknejad, “Advanced Communication Integrated Circuits” UC Berkeley, 2015.



FRIIS PROPAGATION EQUATION



Received power $P_r = G_t \frac{P_t}{4\pi r^2} A_{er}$

TX power over surface area of sphere

Effective aperture of the RX

$$A_{er} = \frac{\lambda^2}{4\pi} G_r$$

$$\frac{P_r}{P_t} = \frac{A_{e1} A_{e2}}{r^2 \lambda^2} = \frac{G_t G_r}{\left(\frac{4\pi r}{\lambda}\right)^2}$$

- G_t : Gain of TX antenna
- G_r : Gain of RX antenna
- r : Line of sight distance

Ali Niknejad, "Advanced Communication Integrated Circuits" UC Berkeley, 2015.



FRIIS PROPAGATION EQUATION

$$\frac{P_r}{P_t} = \frac{G_t G_r}{\left(\frac{4\pi r}{\lambda}\right)^2} = \frac{G_t G_r}{\left(\frac{4\pi r f_c}{c}\right)^2}$$

$$P_r|_{dB} = P_t|_{dB} + G_t|_{dB} + G_r|_{dB} + 20 \cdot \log_{10} \frac{\lambda}{4\pi r}$$

- For a fixed antenna gain (directivity), the attenuation increases as f^2
 - Capture area at RX antenna is proportional to λ^2 , which is decreasing with f



FRIIS PROPAGATION EQUATION

$$\frac{P_r}{P_t} = \frac{G_t G_r}{\left(\frac{4\pi r}{\lambda}\right)^2} = \frac{G_t G_r}{\left(\frac{4\pi r f_c}{c}\right)^2}$$

$$P_r|_{dB} = P_t|_{dB} + G_t|_{dB} + G_r|_{dB} + 20 \cdot \log_{10} \frac{\lambda}{4\pi r}$$

- If we had fixed area for the antenna, the antenna gain (directivity) needs to increase with frequency
 - Realized using dish antenna or an 'antenna array'
 - More on antenna array later (Section 2.9 in the textbook)

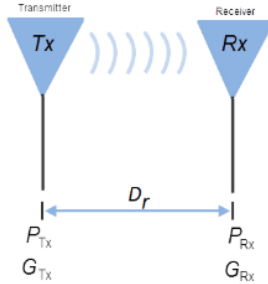


RX POWER

Transmitter Power:	10	dBm	▼
Transmitter Gain (dBi):	5		
Frequency:	2.1	GHz	▼
Distance:	5	Kilometers	▼
Receiver Gain (dBi):	2		
<input type="button" value="Calculate"/>			

Result:

Received Power: -95.87 dBm

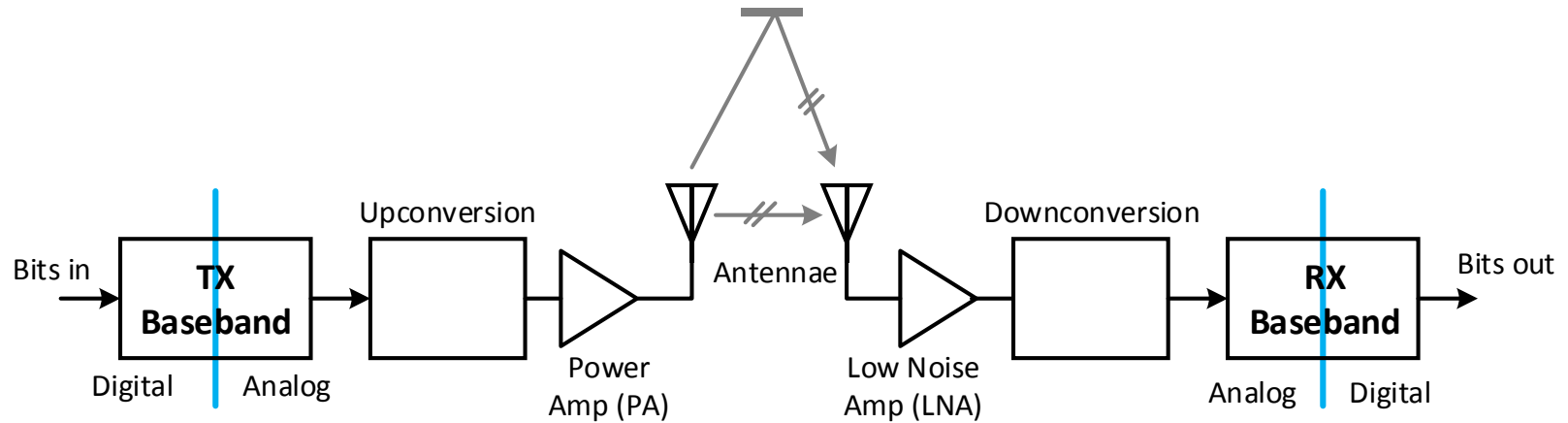


Friis Calculator: <https://www.pasternack.com/t-calculator-friis.aspx>

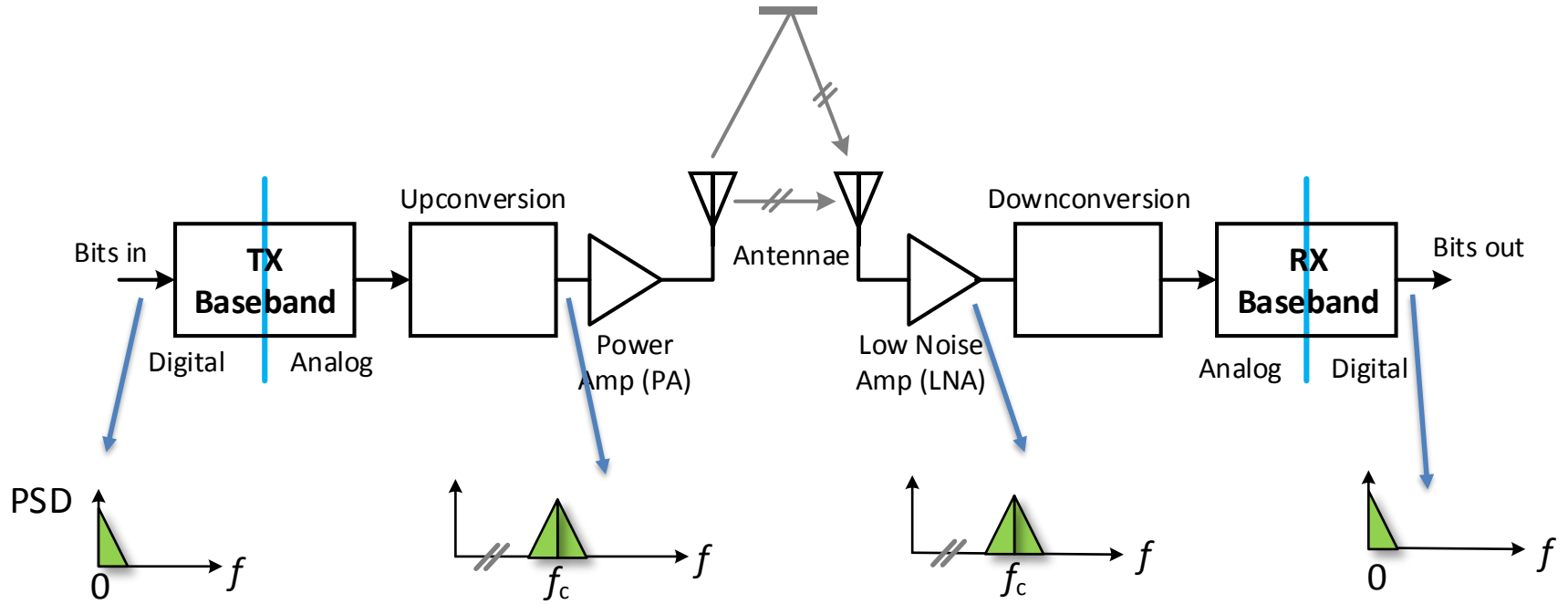
- Received signal is very weak, typically **-80dBm** to **-120dBm**
- Often drowned by large interferers (say $>0\text{dBm}$).



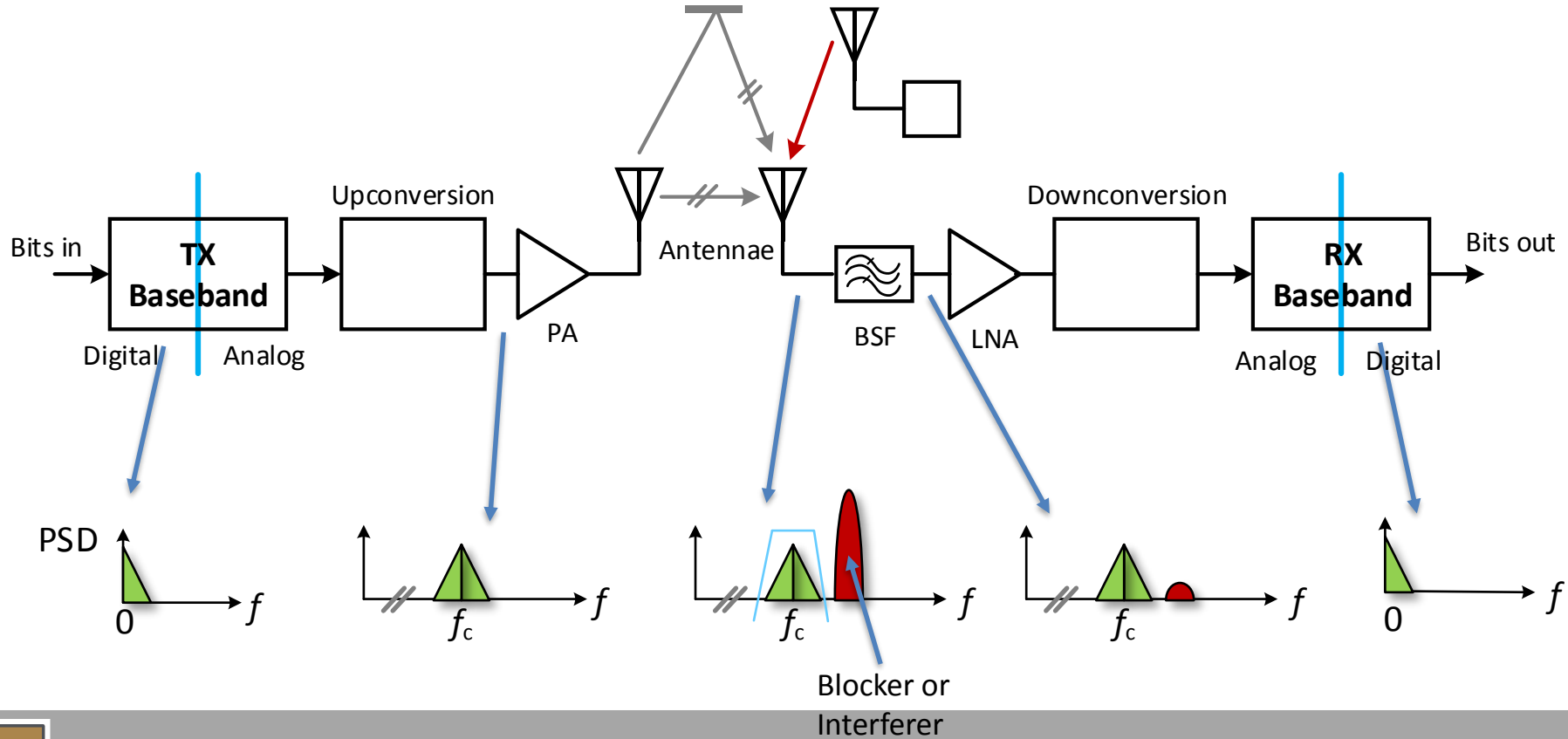
RF TRANSCEIVERS



RF TRANSCEIVERS

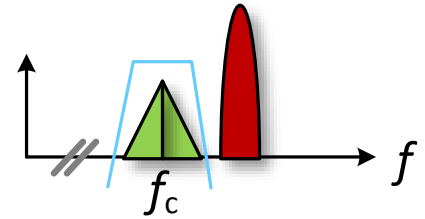


RF TRANSCEIVERS



RADIO TRANSCEIVERS

- A transmitter modulates a baseband signal to a higher carrier frequency and feeds an antenna with sufficient power
 - Should not distort the TX signal too much
- A well-designed receiver should perform
 - **High-gain amplification** of the received signal
 - Highly **selective filtering** of the desired signal
 - Reject adjacent channels, interferers, and image signal
 - Recovery of the intended information within error limits
- Processing narrowband analog signals with high selectivity and dynamic range

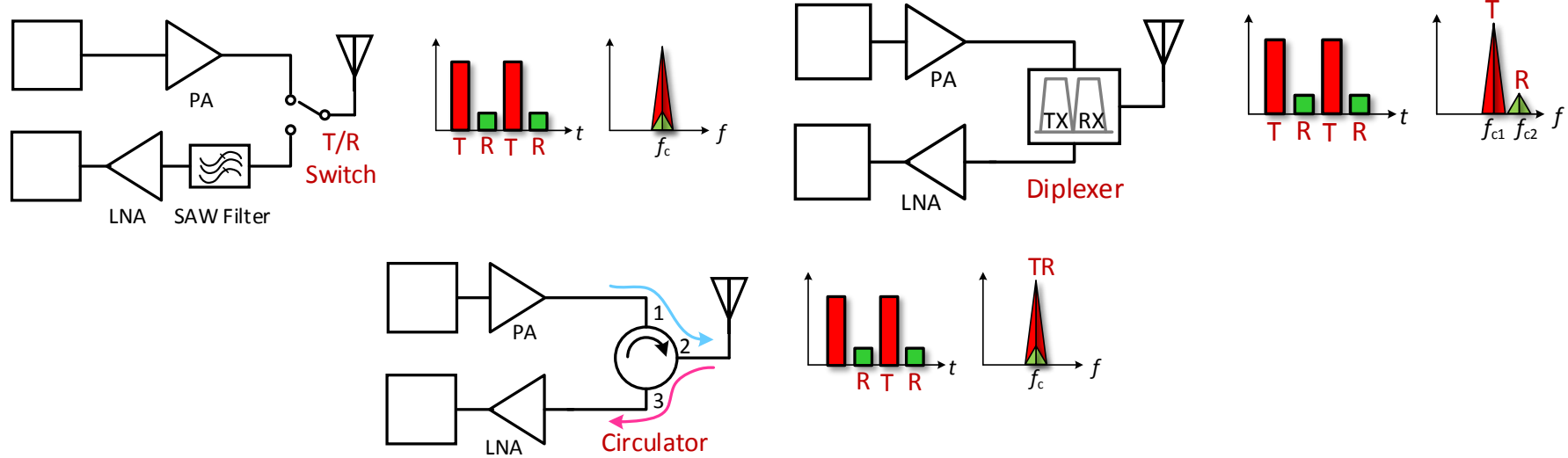


RADIO TRANSCEIVERS: ISOLATION

- Usually TX and RX don't operate simultaneously at the same carrier frequency
 - Frequency-division multiplexing (FDD) or
 - Time-division multiplexing (TDD) schemes used
 - Other methods of isolation
- Selectivity achieved using off-chip filters (SAW or MEMS)
- Isolation between TX and RX achieved using off-chip **diplexers** and **isolators/circulators**



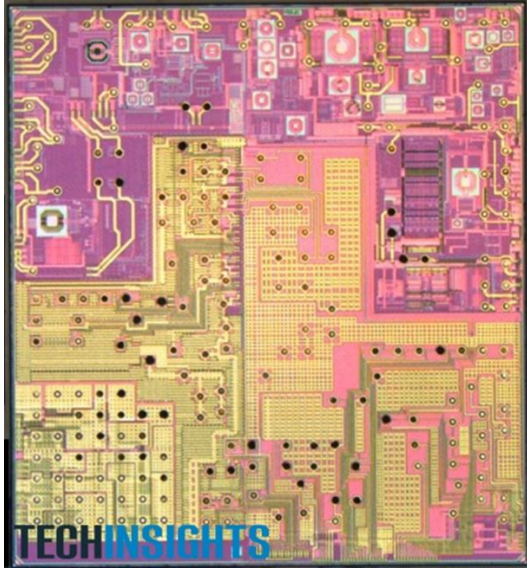
RF TX/RX ISOLATION



- Isolation usually not sufficient for simultaneous TX and RX
 - TX leaks to RX through package coupling and reflections
- Search **full-duplex radios** online for recent advances!

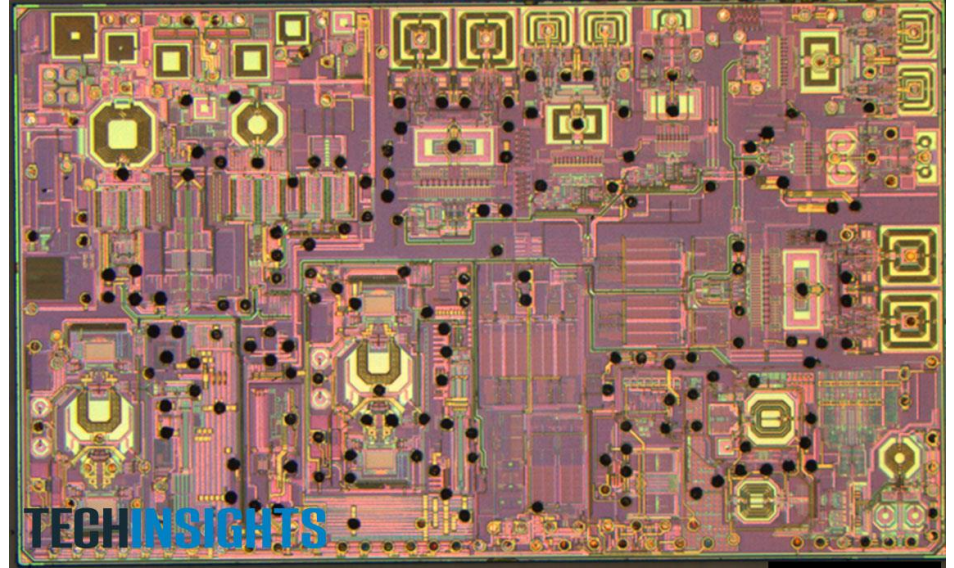


COMMERCIAL RFICS



BCM 4330 – Mobile Wireless

Single-band 2.4 GHz 802.11 b/g/n or dual-band 2.4 GHz and 5GHz 802.11 a/b/g/n Integrated ARM® Cortex™-M3 processor and on-chip memory.



Qualcomm RTR8600 chip

Multi-band Multi-mode RF transceiver found in prominent Smartphones

